Agric Res J **53** (3) : 295-302, *September* 2016
DOI No. 10.5958/2395-146X.2016.00058.2

Review Paper

APPLICATION OF REMOTE SENSING AND GIS IN AGRICULTURE AND NATURAL RESOURCE MANAGEMENT UNDER CHANGING CLIMATIC CONDITIONS

P K Kingra*, Debjyoti Majumder and Som Pal Singh

School of Climate Change and Agricultural Meteorology
Punjab Agricultural University, Ludhiana – 141 004

ABSTRACT

Agricultural production systems are highly vulnerable to variations in climate, soil and topography of different regions. For sustainable agricultural management, all these factors need to be analysed on spatio-temporal basis. The advanced techniques like remote sensing, global positioning system and geographical information system can be of great use for their assessment and management. Remote sensing and GIS are very important tools having wide range of applications to tackle these issues. These technologies have manifold applications in agriculture including crop discrimination, crop growth monitoring / stress detection, crop inventory, soil moisture estimation, computation of crop evapo-transpiration, site-specific management / precision agriculture, crop acreage estimation and yield prediction. Timely and reliable information on crop acreage, growth condition and yield estimation can be highly beneficial to the producers, managers and policy planners for taking tactical decisions regarding food security, import/export and economic impact. Such information on regional basis can be made available with the use of remote sensing and GIS techniques. Remote sensing and GIS can also be used very effectively in land use / land cover analysis as well as damage assessment because of drought, floods and other extreme weather events An attempt has been made in the present study to review, analyse and evaluate the latest information regarding the application of remote sensing techniques for crop monitoring, crop condition assessment and yield estimation for sustainability of agriculture and natural resources under changing climatic scenarios.

Key words: Climate change, Crop acreage estimation, Crop growth monitoring, Crop yield prediction, Geographical information system, Remote sensing

Global warming resulting from green house effect has threatened the sustainability of natural resources and agriculture in many regions over the earth's surface. Significant rise in extreme weather events has been observed globally in the recent past. Nilam cyclone of 2012, Uttrakhand landslides and floods of 2013 and Hudhud cyclone of 2014 are the recent examples of such events in India, which have far reaching long-term socio-economic impacts. Global warming triggered climatic changes and extreme weather events have a significant impact on agriculture. Because of large variations in climatic conditions, crops have to suffer from different types of stresses leading to reduced crop productivity and year to year variability. Under such conditions, rapidly emerging remote sensing and geospatial technology can be of great help for crop growth monitoring, identification and management of different types of stresses and regional yield estimations to sustain the natural resources and agricultural productivity. Atzberger (2013) has illustrated five major applications of remote sensing in agriculture including biomass and yield estimation, vegetation vigor and drought stress monitoring, assessment of crop phenological development, crop acreage estimation and cropland mapping, mapping of disturbances and land use land cover changes in addition to precision agriculture and irrigation management.

Agriculture in India is hindered due to small land-holdings, inadequate resources and lack of agro-technological information. Under the changing climatic scenarios, agricultural planning and use of agricultural technologies need precise spatio-temporal meteorological and crop information for accurate data analyses, forecasts and their effective application in agricultural planning and management decisions, irrigation scheduling, crop stress management and preparedness for calamities and sustainability of natural resources and ecosystems over different regions. The broad objective of sustainable agriculture is to balance the inherent land resources with crop requirements, paying special attention to optimization of resource use towards achievement of sustained productivity over a long period (Lal and Pierce, 1991). Although the conventional methods of acquiring weather and crop growth status information are reliable, but they are labour intensive and time consuming. However, recently remote sensing (RS) and geographical information system (GIS) technologies are gaining importance for acquiring spatio-temporal meteorological and crop status information for complementing the traditional methods. Remote sensing data can greatly contribute to the monitoring by providing timely, synoptic, cost-efficient and repetitive information about the earth's surface (Justice *et al.*, 2002).

Under the changing climatic conditions, quick spatio-temporal assessment of extreme weather events and crop growth status including crop stress detection and damage

*Corresponding author : pkkingra@pau.edu
Date of receipt : 28.12.2015, Date of acceptance : 29.07.2016

assessment is difficult using conventional methods. Under such conditions, geospatial technology i.e. Remote sensing and GIS are highly applicable for acquisition and management of huge spatio-temporal data by using satellite information, digital maps and simulation models etc. This technology is highly advantageous because of rapid and repetitive data availability, quick analysis and generation of valuable information for decision-makers and policy planners. Remote sensing technology has the potential of revolutionizing the detection and characterization of agricultural productivity based on biophysical attributes of crops and/or soils (Liaghat and Balasundram, 2010). Data recorded by remote sensing satellites can be used for yield estimation (Bernerdes *et al.*, 2012; Doraiswamy *et al.*, 2005), acreage estimation (Golford *et al.*, 2008), crop phenological information (Sakamoto *et al.*, 2005), detection of stress situations (Gu *et al.*, 2007) and disturbances.

Remote sensing provides a cheap alternative for data acquisition over large geographical areas (De beurs and Townsend, 2008). Remote sensing along with GIS is highly beneficial for creating spatio-temporal basic informative layers and generating valuable integrated information by superimposing different basic layers. This technology can be successfully applied to diverse fields including floodplain mapping, hydrological modeling, surface energy flux, urban development, land use changes, crop growth monitoring and stress detection. Today, remote sensing is potentially a practical management tool for site-specific crop management in precision agriculture (Casady and Palm, 2002). Keeping in view the importance of remote sensing and GIS technology under changing climatic conditions, the relevant literature on application of remote sensing and GIS for sustainability of agriculture and natural resources is reviewed and reported in the present manuscript.

Basic aspects

The basic concept of data acquisition through remote sensing revolves around the spectral reflectance characteristics of different surface features. The advent of multispectral and hyperspectral remote sensing technology has widened its applications in different fields. These technologies are highly applicable in agriculture because multispectral reflectance and temperatures of the crop canopies are related to two important plant physiological processes i.e. photosynthesis and evapotranspiration. Chlorophyll pigment absorbs mainly in the Blue and Red part of the electromagnetic spectrum and reflects the green (Chappelle *et al.*, 1992) (Fig. 1). The percentage of radiation reflected from the leaf is higher in the NIR than in the green (Gausman *et al.*, 1971). The spectral behaviour of the leaf changes during senescence and in plants subjected to stress (e.g disease, pest, N shortage) by reflecting more red light and absorbing more NIR. Opposite behavior is shown in healthy plants with high values of reflectance in the NIR region and low values in red portion (Pinter *et al.*, 2003).

Similarly, soil reflects less in the blue region, but its reflectance properties increase monotonically in the visible and NIR regions of the spectrum (Price, 1990). Spectral properties of the soil mainly depend on soil constituents such as soil organic matter, iron oxides and moisture, and soil roughness such as particle and aggregate size. High soil water and high organic matter contents show lower reflectance while soils with low water content and smooth surface tend to be brighter (Daughtry, 2001). In the presence of iron oxides, soil reflectance is higher in the red portion of the spectrum. Crop residues on soil surface also cause variation in reflectance as compared to bare soil and partial canopy cover (Daughtry *et al.*, 1996; Nagler *et al.*, 2000; Barnes *et al.*, 2003). Similarly, interaction of electromagnetic radiation with crops is influenced by chlorophyll and water content in optical region, whereas crop geometry and dielectric property influences the response in microwave region. Thus, based on the spectral reflectance characteristics, different surface features and their properties can be assessed by using remote sensing techniques.

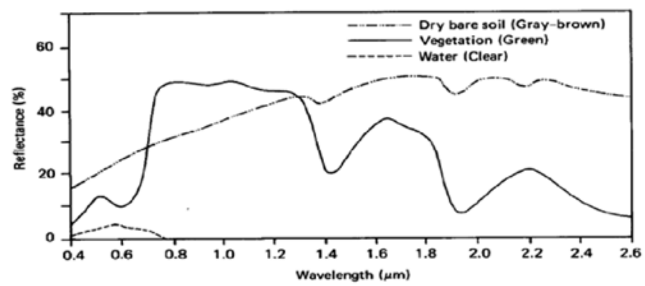

Fig. 1. Spectral signatures of different surface features

Crop inventory

The science of remote sensing can play a pivotal role in crop identification and area estimation and, therefore, has a significant role in inventorying data base on different crops. A number of studies using aerial photographs and digital image processing techniques have been reported in literature. It helps in reducing the amount of the field data to be collected and provides higher precision of the estimate. Pan *et al.* (2009) used Quick Bird imagery and a Production Efficiency Model (PEM) to estimate crop yields in Zhonglianchuan, a hilly area on Loess Plateau, China. In the PEM model, crop yields were a function of the Photosynthetically Active Radiation (PAR), fraction of Absorbed Photosynthetically Active Radiation (fAPAR) and Light Use Efficiency (LUE). Results showed that Quick Bird imagery improved the yield estimation accuracy. The information extracted from the image was highly correlated to estimated yields from ground data collection (r^2 = 0.86). Kurtz *et al.* (2009) used multi-temporal LANDSAT imagery in order to classify land cover types and grazing intensity. Grazing intensity categories were defined based on percentage of bare soil, sward height and standing dead material. Correlation analysis between spectral ratio, i.e. Normalized Difference Vegetation Index (NDVI) and above ground biomass was significant. Meanwhile, in some other studies Synthetic Aperture Radar (SAR) data was utilized to quantify biomass in a wetland for the purpose of optimizing livestock management. The signal sensitivity corresponding to biomass variation was high enough to facilitate high accuracy biomass mapping.

Physiological studies

Remote sensing data have been exploited to estimate canopy characteristics by using empirical approaches based on spectral indices (D'Urso *et al*., 2004; Schlerf *et al*., 2005). Different properties such as plant density, leaf area index, chlorophyll content etc. (Asner, 1998; Datt, 1998; Ceccato *et al*., 2001; Champagne *et al*., 2003; Gupta *et al*., 2003; Merzlyak *et al*., 2003; Pu *et al*., 2003; Stimson *et al*., 2005; Chun-Jiang *et al*., 2006) can be estimated using hyperspectral imagery. These studies investigated the spectral reflectance properties of the plants, identifying key spectral wavebands related to specific plant physiological and structural characteristics, hence deriving sensitive vegetation spectral indices for their non-destructive estimation. Analysis of hyperspectral remote sensing data has been carried out to estimate LAI for agricultural crops and forests. Schlerf *et al.* (2005) investigated several narrow and broad band vegetation indices in order to explore the possibolity of hyperspectral data to improve the estimation of biophysical variables such as LAI, canopy crown and crown volume when compared to multispectral analyses.

The spectral and spatial information content of the satellite data was exploited to validate canopy reflectance models such as PROSPECT and SAILH (D'Urso *et al*., 2004). Results obtained for the crops under investigation encourage the use of canopy reflectance models in the inverse mode in order to retrieve other vegetation parameters such as chlorophyll content, dry matter and canopy geometrical characteristics like mean leaf inclination angle. The accurate estimation of plant water status and plant water stress is essential for the integration of remote sensing into precision agricultural and forestry management. The potential to spectrally estimate plant physiological properties over relatively large areas, and to predict plant water status and plant water stress has been demonstrated for agricultural crops (Champagne *et al*., 2003) and forestry species (Stimson *et al*., 2005). These studies indicated the potential use of vegetation spectral indices derived from various scales of remote sensing data for determining plant physiological properties and improving estimates of plant physiological and structural characteristics from hyperspectral data, allowing for much more detailed spectral analyses and hence more accurate estimates.

Monitoring of vegetation status

Remote sensing of soil and crop can be an attractive alternative to the traditional methods of field scouting because of the capability of covering large areas rapidly and repeatedly providing spatial and temporal information necessary for sustainable soil and crop management (Basso *et al*., 2004). The potential of remote sensing in agriculture is very high because of its ability to infer about soil and vegetation cover as a non-destructive mean. Numerous spectral vegetation indices (VIs) have been developed to characterize vegetation canopies. A most significant intellectual challenge to ecologists and bio-geographers is to understand spatio-temporal patterns of vegetation (Liu, 2007). Omuto (2011) while tracing the footprint of vegetation dynamics modelled a relationship between Advanced Very High Resolution Radiometer (AVHRR) / Moderate Imaging Spectro-radiometer (MODIS) NDVI and rainfall using regression analysis. Results showed a high correlation between rainfall and NDVI which proved that vegetation trend monitoring with RS and GIS can give accurate indication of climate change. Eckert *et al*. (2011) assessed aboveground biomass and carbon stock for degraded forest in the Analanjirofo region, North East of Madagascar. Carbon stock within the two classes were calculated and linked to a multi-temporal set of SPOT satellite data acquired in 1991, 2004 and 2009 together with forest prediction for 2020 for the study area.

Precision agriculture

Remote sensing technology is a key component of precision farming and is being used by an increasing number of scientists, engineers and large-scale crop growers (Liaghat and Balasundram, 2010). Precision farming aims at reduced cost of cultivation, improved control and improved resource use efficiency through information received by the sensors fitted with the farm machineries. Variable rate technology (VRT) is the most advanced component of precision farming. Sensors are mounted on the moving farm machineries containing a computer which provides input recommendation maps and thereby controls the application of inputs based on the information received from GPS receiver (NRC, 1997).

Nutrient and water stress

Nutrient and water stress management is one of the most important fields where we can opt for application of remote sensing and GIS through the application of precision farming. Detecting nutrient stresses using remote sensing and GIS can help in site specific nutrient management and thereby can reduce the cost of cultivation as well as increase the fertilizer use efficiency. In the semi-arid and arid regions, judicious use of water can be possible through adaptation of precision technologies. For example drip irrigation coupled with information from remotely sensed data such canopy-air temperature difference can be used to increase the water use efficiency by reducing the runoff and percolation losses (Das and Singh, 1989). Development in remote sensing data acquisition capabilities, data processing and interpretation of ground based, airborne and satellite observations have made it possible to couple RS technologies and crop management systems to improve nutrient and water use efficiency. Mukherjee *et al.* (2014) standardized the spectral reflectance characteristics of wheat under water stress conditions. The spectral reflectance in the visible region was higher in water stressed crop than the non-stressed. The vegetation indices like NDVI, RVI, PVI and GI were found lower for stressed and higher for non-stressed crop.

Pest infestation

The remote sensing approach in assessing and monitoring insect defoliation has been used to relate differences in spectral responses to chlorosis, yellowing of leaves and foliage reduction over a given time period assuming that these differences can be correlated, classified and interpreted (Franklin, 2001). The range of remote sensing applications has included detecting and mapping defoliation, characterization of pattern disturbances etc. and providing data to pest management decision support system (Lee *et al*., 2010). The possibility of forecasting and vulnerability of forest tress to insect defoliation has also been reported as tool for timely management (Luther *et al*., 2004). William *et al.* (1979) evaluated different types of vegetation indices on Landsat imagery acquired before and after defoliation to differentiate between healthy and unhealthy vegetation cover. Hall *et al.* (2003) also used Landsat multi-temporal change detection approach to map defoliated forest of Canada which showed similar results with other studies being carried out. Clerke and Dull (1990), determined the extent and severity of gypsy moth infestation in Virginia using imagery acquired by SPOT. Insect defoliation outbreak has also been studied using MODIS data (Kharuk *et al*., 2007). De beurs and Townsend (2008) concluded that MODIS data represent an important tool for insect damaged defoliation and determination of vegetation indices in plot scale.

Riedell *et al.* (2004) reported remote sensing technology as an effective and inexpensive method to identify pest-infested and diseased plants. They used remote sensing techniques to detect specific insect pests and to distinguish between insect and disease damage on oat. They suggested that canopy characteristics and spectral reflectance differences between insect infestation damage and disease infection damage can be measured in oat crop canopies by remote sensing.

Weed identification and management

Based on the variation in spectral reflectance characteristics of weeds and crops, remote sensing technology provides a means of identification of weed infestation in the crop stand and further aids in the development of weed maps by detecting the location of weeds within an agricultural field, so that site-specific/need based herbicide can be applied. Kaur *et al.* (2013) reported higher radiance ratio and NDVI values in solid stand or pure wheat and minimum under solid weed plots. It was observed that by using radiance ratio and NDVI, pure wheat can be distinguished from pure populations of Rumex spinosus beyond 30 DAS. Different levels of Rumex populations could be discriminated amongst themselves from 60 DAS onwards.

Water resource management

In the recent decades, the scarcity of water resources is being experienced at global and regional level and, therefore, needs to be managed judiciously by applying the state of the art technologies. Remote sensing is one of the effective tools for assessing and monitoring the water resources. This technology has been widely used in water resource applications (Gitelson and Merzlyak, 1996; Zagolski *et al*., 1996; McGwire *et al*., 2000; Coops *et al*., 2002; Underwood *et al*., 2003) and in particular, hyperspectral remote sensing is emerging as the more in-depth means of investigating spatial, spectral and temporal variations in order to derive more accurate estimates of information required for water resource applications. The advent of microwave remote sensing has made possible the assessment of soil moisture availability from remote sensing data.

Flood monitoring

Satellite remote sensing allows timely investigation for large regions and provides frequent imaging of the region of interest. Until recently, near real-time flood detection was not possible, but with sensors such as Hyperion on board the EO-1 satellite, this has been significantly improved. Automated spacecraft technology has reduced the time to detect and react to flood events in a few hours (Felipe *et al.,* 2006). Advances in remote sensing have resulted in the investigation of early warning systems with potential global applications. Most recent studies from NASA and the US Geological Survey are utilising satellite observations of rainfall, rivers and surface topography into early warning systems by employing satellite microwave sensors to gauge discharge from rivers by measuring changes in river widths and satellite based estimates of rainfall to improve warning sytems (Brakenridge *et al*., 2006).

Glaber and Reinartz (2004) detected flooded areas with satellite data and investigated moisture classes in flood plain areas in relation to water changes, accumulation of sediments and silts for different land-use classes and erosive impacts of floods. Roux and Dartus (2006) also estimated discharge and flood hydrographs from hydraulic information obtained from remotely sensed data. Optimisation methods were also used to minimise discrepancies between simulations and observations of flood extent fields to estimate river discharge.

Estimation of evapo-transpiration

Estimation of evapotranspiration (ET**)** is essential for water resource management such as water and energy balance computations, irrigation scheduling, reservoir water losses, runoff prediction, meteorology and climatology (Medina *et al*., 1998). Estimation of spatial variability in evapo-transpiration is possible over a wide area by using remotely sensed information coupled with surface energy balance algorithms,. The energy emitted from cropped area has been proven beneficial in assessing crop water stress as the temperature of most plant leaves are mediated by soil water availability and crop evapo-transpiration. Batra *et al.* (2006) estimated evaporative fraction (EF), defined as the ratio of ET and available radiant energy, by successfully using AVHRR and MODIS data. Several studies (Kite and Droogers, 2000; Loukas *et al*., 2005; Eichinger *et al*., 2006) have been conducted using more detailed hyperspectral data, ancillary surface data and atmospheric data for improved spatial ET estimates.

The availability of water, radiant energy and the removal of water vapour away from the surface are the major factors that control ET. However these factors in turn depend on other variables such as soil moisture, land surface temperature, air temperature, and vegetation cover, vapour pressure, and wind speed which may vary between regions, seasons, and time of day. Generally these factors are accounted for by using a combination of remote sensing data, ancillary surface data and atmospheric data for the estimation of ET values and has lead to extensive measurements of surface fluxes, meteorological and soil variables (Wang *et al*., 2006). Batra *et al.* (2006) successfully estimated ET based on the extension of the Priestly-Taylor equation and the relationship between remotely sensed surface temperature and vegetation spectral indices. Folhes *et al.* (2009) employed Landsat imagery in conjunction with an evapotranspiration model to measure water use levels in an irrigated area in the semi-arid northeast region of Brazil. Results showed that the combination approach of remote sensing and process modeling produced better predictability of water consumption in irrigated agriculture, and hence improved water resource management in irrigated areas. Ines *et al.* (2006) combined Landsat7 ETM+ images and derived distributed data such as sowing dates, irrigation practices, soil properties, depth to groundwater and water quality as inputs in exploring water management options in Kaithal, Haryana, India during 2000–2001 dry season. They revealed that under limited water conditions, regional wheat yield could improve further if water and crop management practices are considered simultaneously and not independently.

Climate change scenarios

Since climate is determined by a complex set of physical, chemical, and biological elemental interactions among the atmosphere, the hydrosphere and lithosphere, making understanding and forecasting climate change a challenging task (Hartmann, 1994). The climatic conditions on the earth have been and will ever be changing. Amid the dire warnings of severe weather perturbations and global warming, scientists and policy makers have been searching for ways to tackle the threats of climate change. It is therefore, pertinent to understand the dynamic influence of climate perturbations in these spheres both in real time and at synoptic level. Human adaptation for such challenges will require a synergy of data collection and analytical methods which are capable of capturing and processing data at a faster rate. Under such conditions, remote sensing and GIS have found wide applications in climate change analyses and adaptations. Remote sensing enables the acquisition of large-scale comprehensive datasets whereas GIS provides a means of displaying, overlaying, combining data from other sources and analysing the data (Chapman and Thornes, 2003).

The large collection of past and present remote sensing imageries makes it possible to analyse spatio-temporal pattern of environmental elements and the impact of human activities in past decades. For climate change analysis, remote sensing is a required tool for up-to-date environmental data acquisition both at local and synoptic levels. Scientists are now using satellite instruments to locate sinks and sources of CO_2 in the ocean and land (Science, 2007). GIS on the other hand has a very important role to play in environmental monitoring and modelling for combining distributed field-based measurements and remotely sensed data (Larsen, 1999). Chapmann and Thornes (2003) submitted that climatological and meteorological phenomena are naturally spatially variable, and hence GIS represents a useful solution to the management of vast spatial climate datasets for a wide number of applications.

Atmospheric dynamics

Among other applications, early civilian satellite instruments were launched largely to meet the needs of weather forecasting, (Sherbinin *et al.*, 2002). Meteorological satellites are designed to measure emitted and reflected radiation from which atmospheric temperature, winds, moisture, and cloud cover can be derived. Hecker and Gieske (2004) reported that remote sensing can be used for the determination of the atmospheric radiances, emissivity and surface temperature. Burrows *et al.* (1998) measured the absorption cross-sections of NO_2 using the global ozone monitoring experiment (GOME), which are important as accurate reference data for atmospheric remote-sensing of NO_2 and other minor trace gases. Foster and Rahmstorf (2011) took a time series assessment of global temperature over land and ocean using three surface temperature records and two lower-troposphere temperature records based on satellite microwave data. All the five series showed consistent global warming trends. These results indicate that remote sensing and GIS can be used effectively for global / regional climate change analysis.

LITERATURE CITED

Asner G P 1998. Biophysical and biochemical sources of variability in canopy reflectance. *Remote Sens Environ* **64:** 234-53.

Atzberger C 2013. Advances in remote sensing of agriculture: context description, existing operational monitoring systems and major information needs. *Remote Sens* **5**: 949 – 81.

Barnes E M, Sudduth K A, Hummel J W, Lesch S M, Corwin D L, Yang C, Daughtry C S T and Bausch W C 2003. Remote- and ground-based sensor techniques to map soil properties, *Photogrammetric Engineering & Remote Sensing* **69(6)**: 619–30.

Basso B, Cammarano D and De Vita P 2004. Remotely sensed vegetation indices: theory and applications for crop management. *Rivista Italiana di Agrometeorologia* **(1)**: 36-53.

Batra N, Islam S, Venturini V, Bisht G and Jiang L 2006. Estimation and comparison of evapotranspiration from MODIS and AVHRR sensors for clear sky days over the Southern Great Plains. *Remote Sens Environ* **103:** 1-15.

Bernardes T, Meriera M A, Adami M, Giarolle A and Rudorff B F T 2012. Monitoring biennial bearing effect on coffee yield using MODIS remote sensing imagery. *Remote Sens* 4: 2492 – 2509.

Brackenridge R, Anderson E and Nghiem S V 2006. Satellite microwave detection and measurement of river floods. *NASA Spring Annual General Conference 2006.* www.nasa.gov/vision/earth/lookingatearth/springagu_2006.html (Accessed 4 October 2006).

Burrows J P, Dehn A, Deters B, Himmelmann S, Richter A, Voigt S and Orphal J 1998. Atmospheric remote-sensing reference data from GOME: part 1. Temperature-dependent absorption cross-sections of NO_2 in the 231—794 nm range. *J Quant Spectrosc Radiat Transf* **60 (6)**: 1025-31.

Casady W W and Palm H L 2002. Precision agriculture: Remote sensing and ground truthing. MU Extension, University of Missouri, Columbia.

Ceccato P, Flasse S, Tarantola S, Jacquemoud S and Gregoire J M 2001. Detecting vegetation leaf water content using reflectance in the optical domain. *Remote Sens Environ* **77:** 22-33.

Champagne C M, Staenz K, Bannari A, Mcnairn H and Deguise J C 2003. Validation of a hyperspectral curve fitting model for the estimation of water content of agricultural canopies. *Remote Sens Environ* **87:** 148-60.

Chapman L and Thornes J E 2003. The use of geographical information system in climatology and meteorology. Climate and Atmospheric Research Group, School of Geography and Environmental Science, University of Birmingham, Birmingham B15 2TT, UK.

Chappelle E W, Kim M S and McMurtrey J E 1992. Ratio analysis of reflectance spectra (RARS) – An algorithm for the remote estimation of the concentrations of chlorophyll-a, chlorophyll-b, and carotenoids in soybean leaves. *Remote Sens Environ* **39 (3)**: 239–47.

Chun-jiang Z, Ji-hua W, Liang-yun L, Wen-Jiang H and Qi-Fa Z 2006. Relationship of 2100-2300 nm spectral characteristics of wheat canopy to leaf area index and leaf N as affected by leaf water content. *Pedosphere* **16:** 333-38.

Clerke W and Dull C 1990. Evaluating the utility of SPOT digital imagery for delineating and categorizing gyspy moth defoliation. In: *Protecting Natural Resources with Remote Sensing,* The Third Forest Service Remote Sensing Application Conference, 9-13 April, American Society Of Photogrammetry and Remote Sensing, Tucson, Arizona, pp 22-32.

Coops N, Dury S, Smith M L, Martin M and Ollinger S 2002. Comparison of green leaf eucalypt spectra using spectral decomposition. *Austral J Bot* **50:** 567-76.

D'urso G D, DiniI L, Vuolo F, Alonso L and Guanter L 2004. Retrieval of leaf area index by inverting hyperspectral multiangular CHRIS PROBA data from SPARC 2003. *Proc. 2nd CHRIS Proba Workshop*. 28 to 30 April, ESA/ESRIN, Frascati, Italy.

Das D K and Singh G 1989. Estimation of evapotranspiration and scheduling irrigation using remote sensing techniques. Proc. *Summer Inst. On agricultural remote sensing in monitoring crop growth and productivity*, IARI, New Delhi, 113-17.

Datt B 1998. Remote sensing of chlorophyll a, chlorophyll b, chlorophyll a+b, and total carotenoid content in eucalyptus leaves. *Remote Sens Environ* **66:** 111-21.

Daughtry C S T 2001. Discriminating crop residues from soil by shortwave infrared reflectance. *Agronomy Journal* **93(1)**: 125–31.

Daughtry C S T, McMurtrey J E, Chappelle E W, Hunter W J and Steiner J L 1996. Measuring crop residue cover using remote sensing techniques. *Theoretical and Applied Climatology* **54(1–2)**:17–26.

De beurs K and Townsend P 2008. Estimating the effect of gypsy moth defoliation using MODIS. *Remote Sens Environ* **112**: 3983-90.

Doraiswamy P C, Sinclair T R, Hollinger S, Akhmedov B, Stern A and Prueger J 2005. Application of MODIS derived parameters for regional crop yield assessment. *Remote Sens Environ* **97**: 191 – 202.

Eckert S, Ratsimba H R, Rakotondrasoa L O, Rajoelison L G and Ehrensperger A 2011. Deforestation and forest degradation monitoring and assessment of biomass and carbon stock of lowland rainforest in the Analanjirofo region, Madagascar. *Forest Ecology and Management* **262**: 1996–2007.

Eichinger W E, Cooper D I, Hipps L E, Kustas W P, Neale C M U and Prueger J H 2006. Spatial and temporal variation in evapotranspiration using Raman Lidar. *Adv Water Resour* **29:** 369-81.

Felipe I P, Dohm J M, Baker V R, Doggett T, Davies A G, Castano R, Chien S, Cichy B, Greeley R, Sherwood R, Tran D and Rabideau G 2006. Flood detection and monitoring with the autonomous sciencecraft experiment onboard EO-1. *Remote Sens Environ* **101:** 463-81.

Folhes M T, Renno C D and Soares J V 2009. Remote sensing for irrigation water management in the semiarid Northeast of Brazil. *Agric Water Manage* **96**: 1398-1408.

Foster G and Rahmstorf S 2011. Global temperature evolution 1979–2010. *Environmental Research Letters* **6**: 044022.

Franklin S 2001. *Remote Sensing for Sustainable Forest Management*. Lewis publisher, Boca Raton, Florida, 407 p.

Gausman H W, Allen W A, Cardenas R and Richardson A J 1971. Effects of leaf nodal position on absorption and scattering coefficients and infinite reflectance of cotton leaves (*Gossypium hirsutum* L.) *Agronomy Journal* **63(1)**: 87.

Gitelson A A and Merzlyak M N 1996. Signature analysis of leaf reflectance spectra: algorithm development for remote sensing of chlorophyll. *J Plant Physiol* **148:** 494-500.

Glaber C and Reinartz P 2004. Multitemporal and multispectral remote sensing approach for flood detection in the Elbe-Mulde region. *Acta Hydrochim Hydrobiol* **33:** 5.

Gu Y, Brown J F, Verdin J P and Wardlow B 2007. A five year analysis of MODIS NDVI and NDWI for grassland drought assessment over the central great plains of the United States. *Geophys Res Lett* **34**: L06407.

Gupta R K, Vijayan D and Prasad T S 2003. Comparative analysis of red-edge hyperspectral indices. *Adv Space Res* **32:** 2217-22.

Hall R, Davidson D and Peddle D 2003. Ground and Remote estimation of leaf area index in Rocky Mountain forest stands, kananaskis, Alberta. *Canadian Journal of Remote Sensing* **29**: 411-27.

Hartmann L D 1994. *Global Physical Climatology*. Academic Press, 525 B Street, Suite 1900, San Diego, California 92101-4495, USA.

Hecker C A and Gieske A S M 2004. Thermal remote sensing. In Kerle N, Janssen L L F and Huurneman G C (eds): *Principles of Remote Sensing*, ITC, Netherlands.

Ines A V M, Honda K, Das Gupta A, Droogers P and Clemente R S 2006. Combining remote sensing-simulation modeling and genetic algorithm optimization to explore water management options in irrigated agriculture. *Agric Water Manage* **83**: 221-32.

Justice C O, Townshend J R G, Vermata E F, Masuoka E, Wolfe R E, Saleons N, Ray D P and Morisette J T 2002. An overview of MODIS Land data processing and product status. *Remote Sens Environ* **83**: 3 – 15.

Kaur R, Jaidka M and Kingra P K 2013. Study of optimum time span for distinguishing *Rumex spinosus* in wheat crop through spectral reflectance characteristics. *Proc. Natl. Acad. Sci., India, Sect. B Biol. Sci.* (Published online: 29 October, 2013)

Kharuk V, Rnason K and Dvinskaya M 2007. Evidence of evergreen conifer invasion into larch dominated forests during recent decades in central Siberia. *Eurasian Journal of Forest Research* **10**: 163-71.

Kite G and Droogers P 2000. Comparing evapotranspiration estimates from satellites, hydrological models and field data. *J Hydrol* **229:** 3-18.

Lal R and Pierce M 1991. Soil Management for sustainability. Soil and Water Conservation, Ankeny, Iwo, USA.

Larsen L 1999. GIS in environmental monitoring and assessment. In Longley P. A., Goodchild M. F., Maguire D. J. and Rhind D. W. (eds) *Geographical Information Systems*, Vol. 1, 2nd Edition, John Wiley & Sons, Inc.

Lee W, Alchanatis V, Yang C, Hirafuji M, Moshou D and Li C 2010. Sesning technologies for precision specialty crop production. *Computer and Electronic in Agriculture* **74**: 2-33.

Liaghat S and Balasundram S K 2010. A Review: The Role of Remote Sensing in Precision Agriculture. *American Journal of Agricultural and Biological Sciences* **5 (1)**: 50-55.

Liu Y, Zhang Y, He D, Cao M and Zhu H 2007. Climatic control of plant species richness along elevation gradients in the Longitudinal Range-Gorge Region. *Chinese Science Bulletin*, **52 (2)**: 50-58.

Loukas A, Vasiliades L, Domenikiotis C and Dalezios N R 2005. Basin wide actual evapotranspiration using NOAA/AVHRR satellite data. *Phys Chem Earth* **30:** 69-79.

Luther J, Rowlands A, Niemann O and Merton R 2004. Hyperspectral sensors and applications. In: Advanced Image Processing Techniques for Remotely Sensed Hyperspectral Data, Springer, Berlin pp 11-49.

Mcgwire K, Minor T and Fenstermaker L 2000. Hyperspectral mixture modeling for quantifying sparse vegetation cover in arid environments. *Remote Sens Environ* **72:** 360-74.

Medina J L, Camacho E, Reca J, Lopez R and Roldan J 1998. Determination and analysis of regional evapotranspiration in Spain based on remote sensing and GIS. *Phys Chem Earth* **23:** 427-32.

Merzlyak M N, Solovchenko A E and Gitelson A A 2003. Reflectance spectral features and non-destructive estimation of chlorophyll, carotenoid and anthocyanin content in apple fruit. *Postharvest Biol Technol* **27:** 197-211.

Mukherjee A, Singh S P and Kingra P K 2014. Spectral reflectance characteristics of wheat (*Triticum aestivum* L.) under stressed and non-stressed conditions. In Proceedings of Internationl Symposium on "*New Dimensions in Agrometeorology for Sustainable Agriculture (NASA-2014)* held at GBPUAT, Pantnagar during 16-18 October, 2014.

Nagler P L, Daughtry C S T and Goward S N 2000. Plant litter and soil reflectance. *Remote Sensing of Environment* **71**: 207–15.

NRC 1997. Precision Agriculture in the 21st Century Geospatial and informationtechniques in crop management. National Academy Press, Washington DC. 149p.

Omuto C T 2011. A new approach for using time-series remote sensing images to detect changes in vegetation cover and composition in drylands: a case study of eastern Kenya. *International Journal of Remote Sensing* **32 (21)**: 6025-45.

Pan G, Sun G J and Li F M 2009. Using QuickBird imagery and a production efficiency model to improve. *Environ Model Software* **24**: 510-16.

Pinter Jr P J, Hatfield J L, Schepers J S, Barnes E M, Moran M S, Daughtry C S T and Upchurch D R 2003. Remote sensing for crop management. *Photogrammetric Engineering and Remote Sensing* **69 (6)**: 647 – 64.

Price J C 1990. On the information-content of soil reflectance spectra. *Remote Sensing of Environment* **33(2)**: 113–21.

Pu R, Ge S, Kelly N M and Gong P 2003. Spectral absorption features as indicators of water status in coast live oak leaves. *Int J Remote Sens* **24:** 1799-1810.

Riedell W E, Osborne S L and Hesler L S 2004. Insect pest and disease detection using remote sensing techniques. Proceedings of 7th International Conference on Precision Agriculture. Minneapolis, MN USA. http://www.ars.usda.gov/research/publications/Publications.htm? seq_no_115=166154.

Roux H and Dartus D 2006. Use of parameter optimization to estimate a flood wave: potential applications to remote sensing of rivers. *J Hydrol* **328:** 258-66.

Sakamoto T, Yokozawa M, Toritani H, Shibayama M, Ishitsuka N and Ohno H 2005. A crop phenology detection method using time series MODIS data. *Remote Sens Environ* **96**: 366 – 74.

Schlerf M, Atzberger C and Hill J 2005. Remote sensing of forest biophysical variables using HyMap imaging spectrometer data. *Remote Sens Environ* **95:** 177-194.

Science 2007. *How Satellites Help Us Understand Earth's Carbon Cycle*. Available on-line: www.science20.com/news/how_satellites_help_us_understand_earths_carbon_cycle.

Sherbinin A, Balk D, Yager K, Jaiteh M, Pozzi F, Giri C and Wannebo A 2002. A *CIESIN Thematic Guide to Social Science Applications of Remote Sensing*. Center for International Earth Science Information Network (CIESIN) Columbia University, Palisades, NY, USA.

Stimson H C, Breshears D D, Ustin S L and Kefauver S C 2005. Spectral sensing of foliar water conditions in two co-occurring conifer species: *Pinus edulis* and *Juniperus monosperma*. *Remote Sens Environ* **96:** 108-18.

Underwood E, Ustin S and Dipietro D 2003. Mapping nonnative plants using hyperspectral imagery. *Remote Sens Environ* **86:** 150-16.

Wang K, Li Z and Cribb M 2006. Estimation of evaporative fraction from a combination of day and night land surface temperatures and NDVI: A new method to determine the Priestly-Taylor parameter. *Remote Sens Environ* **102:** 293-305.

Williams D, Stauffer M and Leung K 1979. A forester's look at the application of image manipulation techniques to Landsat data. In: Symposium on Remote Sensing for Vegtation Damage Assessment, February 14-16, Washington, The Society, Falls Church, VA, pp 221-29.

Zagolski F, Pinel V, Romier J, Alcayde D, Gastellu-Etchegorry J P, Giordano G, Marty G, Mougin E and Joffre R 1996. Forest canopy chemistry with high spectral resolution remote sensing. *Int J Remote Sens* **17:** 1107-28.